US Research and Test Reactors

Pieter Mumm

National Institute of Standards and Technology

US Research and Test Reactors

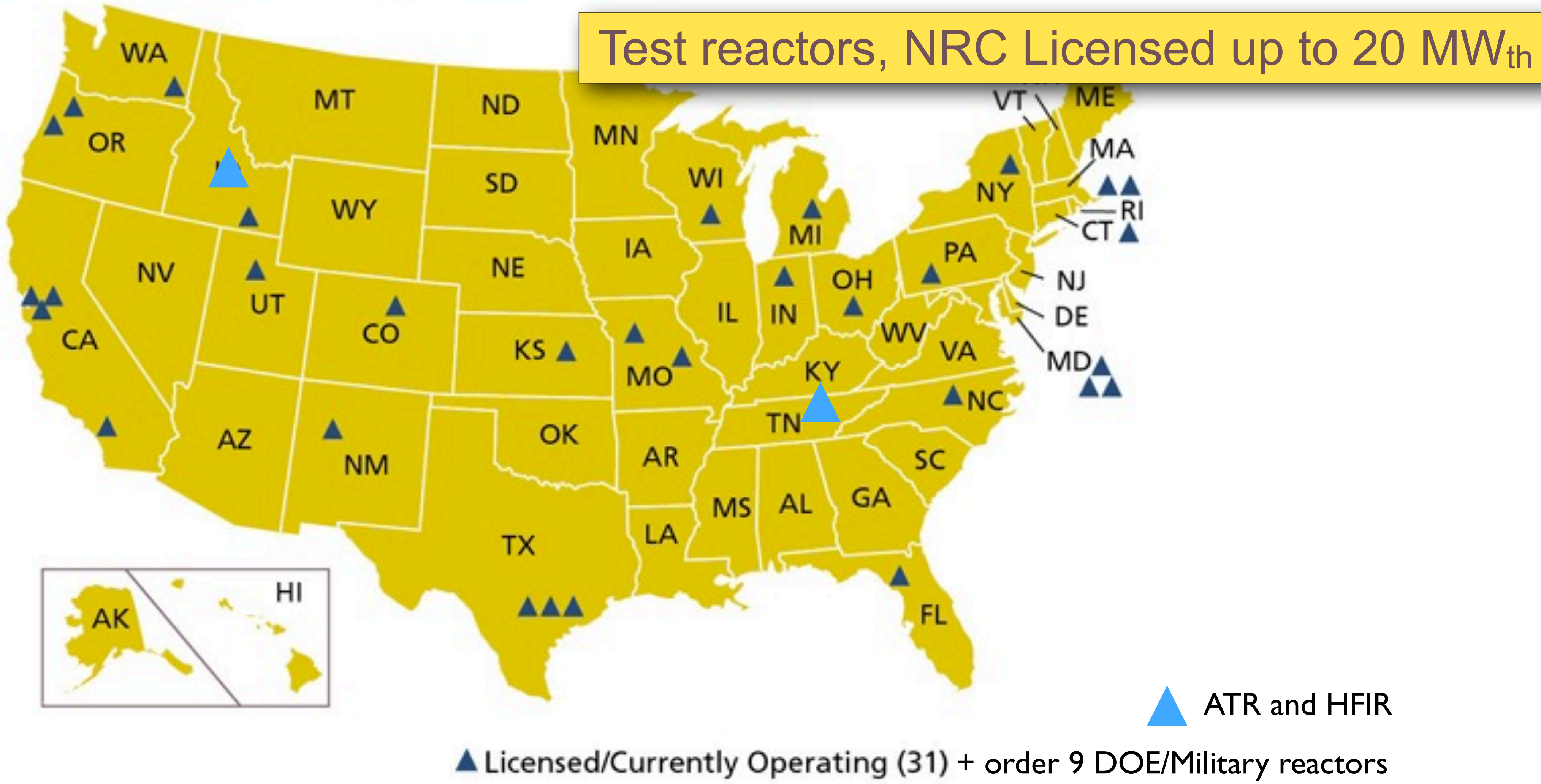
Advantages of Research Reactors for neutrino experiments:

- Potentially HEU fuel (*~constant spectrum, small Pu and ^{238}U contribution*)
- Compact cores (*~meter*)
- User facilities (*well defined schedules, collaboration access*)
- In many cases very well modeled (*models available*)
- Refueling cycles that provide the ability characterize natural backgrounds
- Onsite expertise/engineering/physics groups
- Fundamental science is part of mission

Challenges:

- Relatively low power (*most* $< 1\ MW_{th}$)
- Constrained space near core and reactor correlated backgrounds
- Minimal overburden

US Research and Test Reactors (not including Navy, see next talk)



Research Reactors Are a Unique National Resource

RRs are valuable sources of neutrons providing multidisciplinary research and educational opportunities

These are the 5 US HEU reactors

ATR	Light water, tank	< 250 MW$_{th}$ (120 nom.)
HFIR	Light water, pool	85 MW$_{th}$
NIST	Heavy water, tank	20 MW$_{th}$
Missouri	Light water, pool	10 MW$_{th}$
MIT	LW moderator/HW	5 MW$_{th}$

Idaho National Lab: ATR

The World's Largest Concentration of Reactors:
More than 50 nuclear reactors have been built and operated there--the largest concentration of reactors in the world.

The First Peaceful Use of Nuclear Power:
In 1951, the first usable amounts of electricity were generated by nuclear power by Experimental Breeder Reactor Number I (EBR-I)

Advanced Test Reactor (1967 - present)

Located about 1 hour drive West from INL main campus

Elevation: 1500 m

Primarily mission:
Materials testing and other, prototype reactor work.

USA's only source of Cobalt-60.

ATR
National Scientific User Facility

Flexible design:
"Four Leaf Clover" allows for a variety of testing locations.
Different flux in various locations
Experiments can be run at their own temperature and pressure.

National Scientific User Facility:
Primarily a center for nuclear fuels and materials research

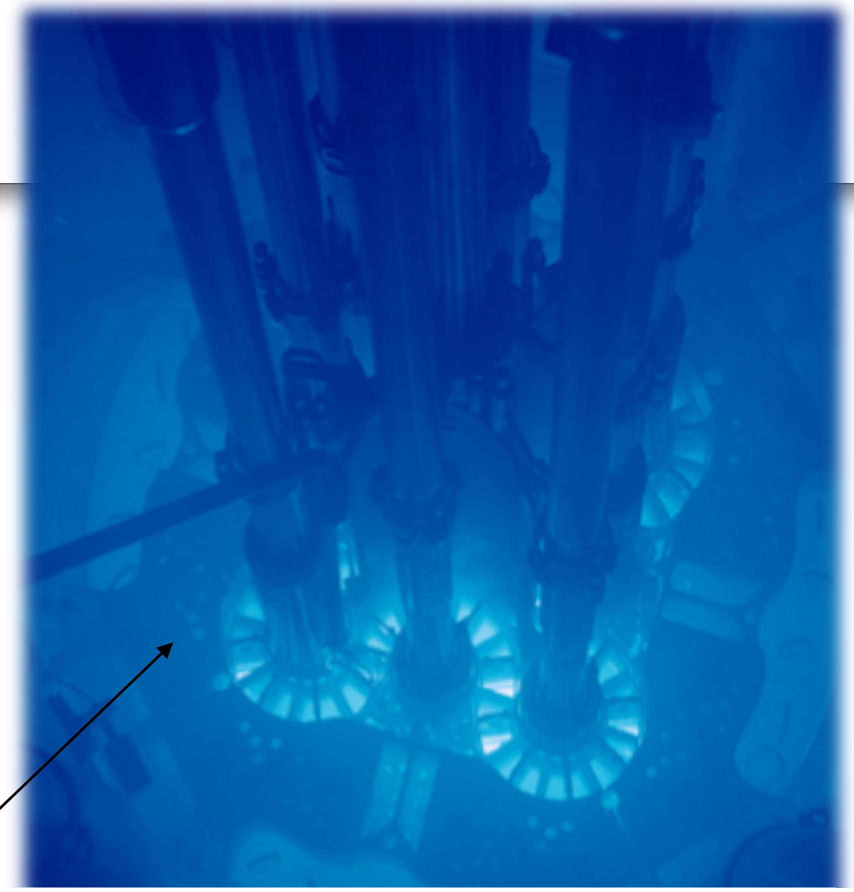
Idaho National Lab: ATR

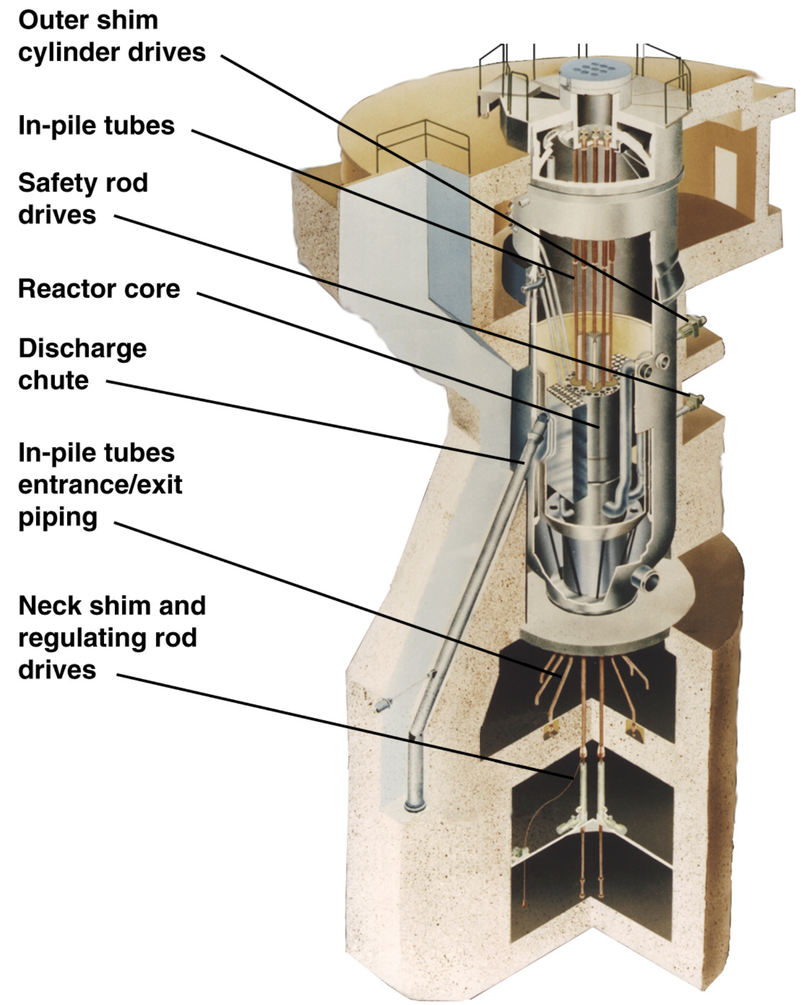
Reactor Type
250 MW_{th} design, Pressurized, light-water moderated and cooled; beryllium reflector (typically power 110 - 120 MW_{th})

Power monitored w/ thermo-hydraulic system
Detailed core model based on the Serpent reactor simulation package: calculated for each cycle

Reactor Vessel
12 ft (3.65 m) diameter cylinder, 36 ft (10.67 m) high stainless steel

Reactor Core
4 ft (1.22 m) (diameter and height)
40 fuel elements
~5.5 m below grade





High neutron flux – 1×10^{15} n/cm^2-s thermal and 5×10^{14} n/cm^2-s fast

Constant axial power profile – rotating control drums instead of vertical control rods

Power tilt capability between all four corners of core ($\leq$3:1 ratio)

Extreme case this is a shift of ~ 7 cm.

Operating Cycles
Standard cycle is 6 - 8 weeks
Occasional short high-power cycles of 2 weeks
Standard outages are 1 - 2 weeks
Operations for approximately 250+ days per year
Core internals change-out every 7 - 10 years

ATR: Multiple Near and far locations

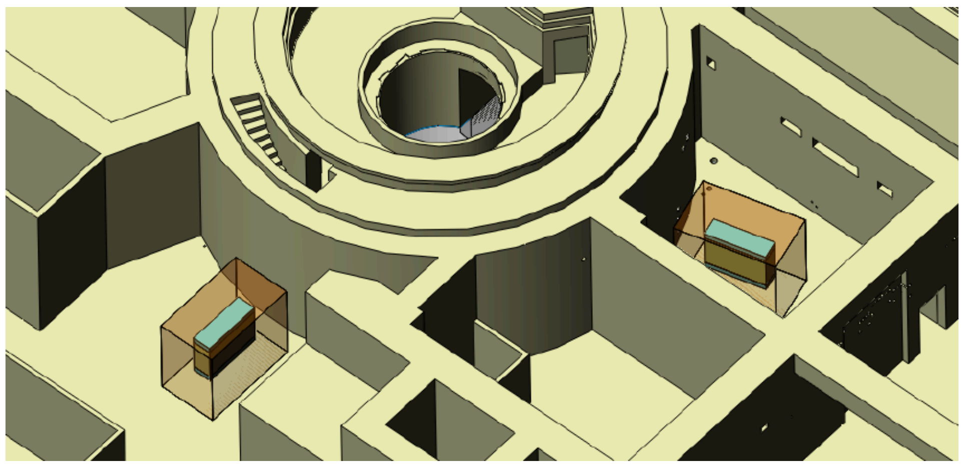
Preferred 'near' location:

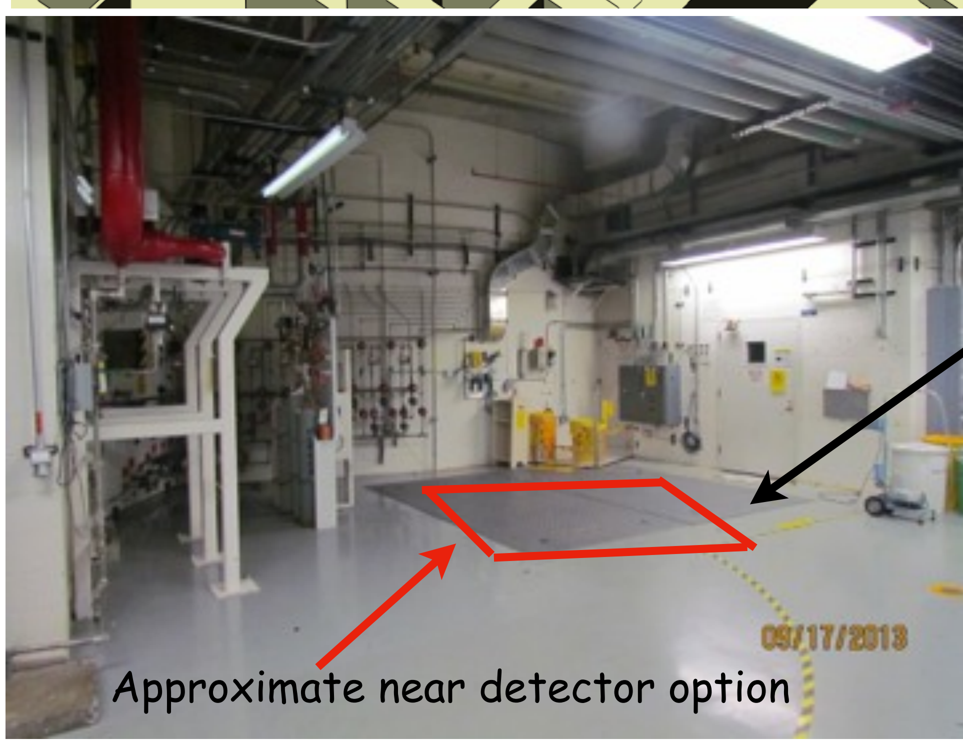
~7 m to core center

5.8 m below grade, no significant height restriction

Access via overhead crane

3500 lb/sqf except over hatch

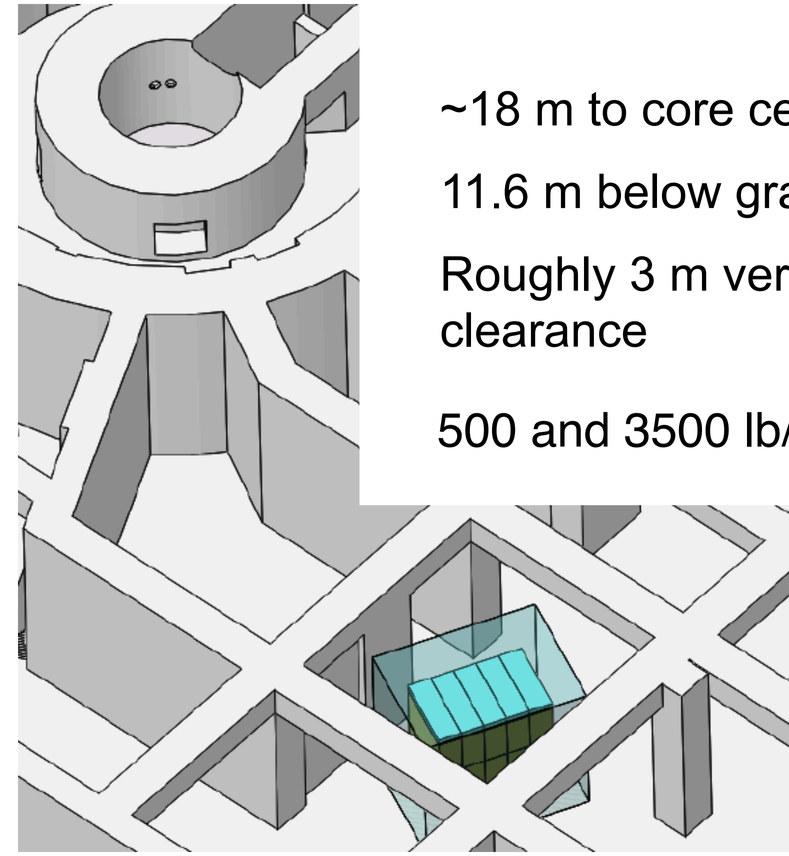




Approximate near detector option

Access hatch

'Far' location: *Staging area*



~18 m to core center

11.6 m below grade

Roughly 3 m vertical clearance

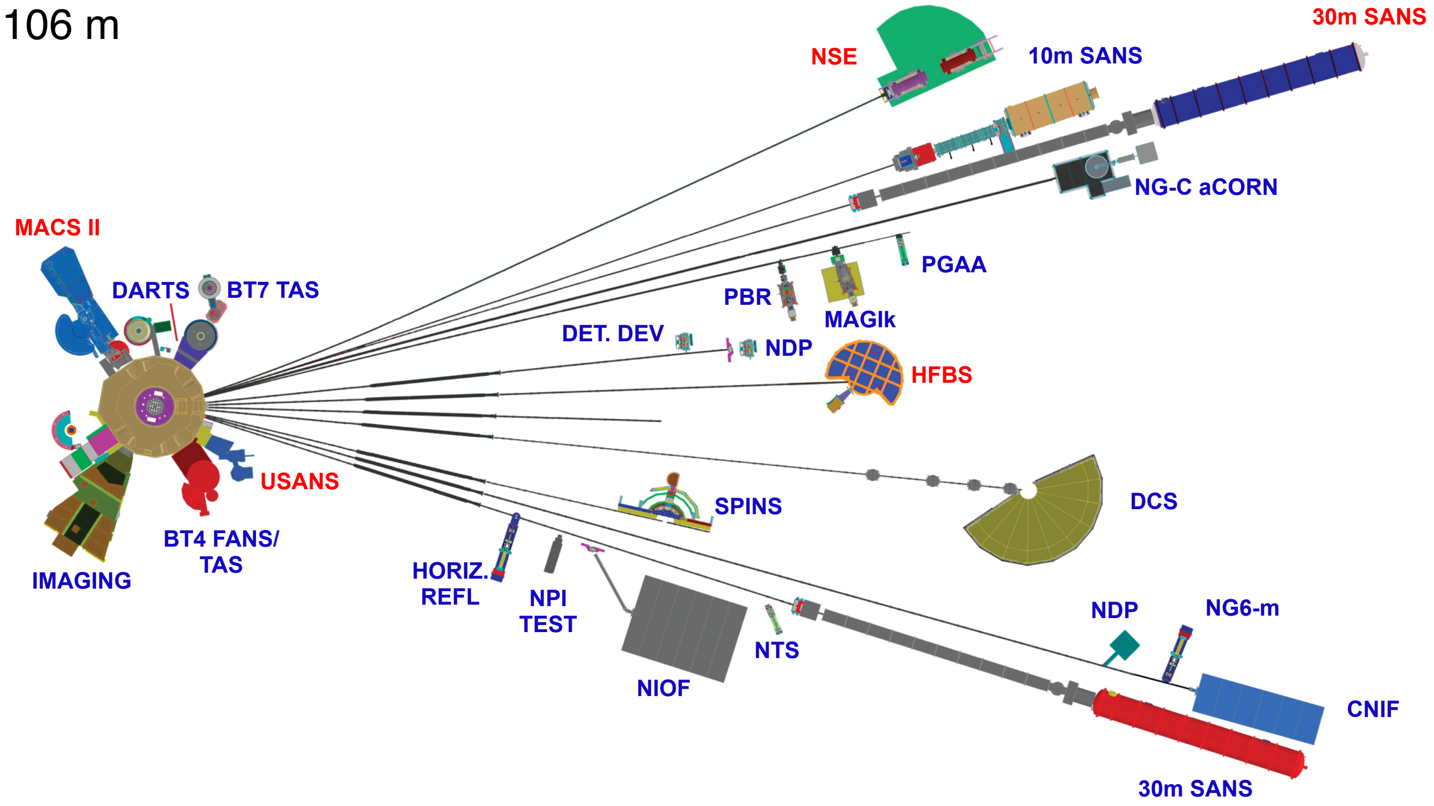
500 and 3500 lb/sqf

Water pipe from core (Na-22 gammas)

US Research and Test Reactors: NIST, NBSR

National Institute of Standards and Technology in Gaithersburg, MD (serviced by 3 major airports)

Elevation: 106 m



US Research and Test Reactors: NBSR

Allen Astin proposed NBSR: 1958

Design FY1961: $0.7M
Construction FY1962: $8.0M
Critical in 1967, 10 MW_{th} regular operations '69
Running at 20 MW_{th} since '84
Just re-licensed

Primary mission of the NCNR is to assure the national availability of neutron measurement capabilities:

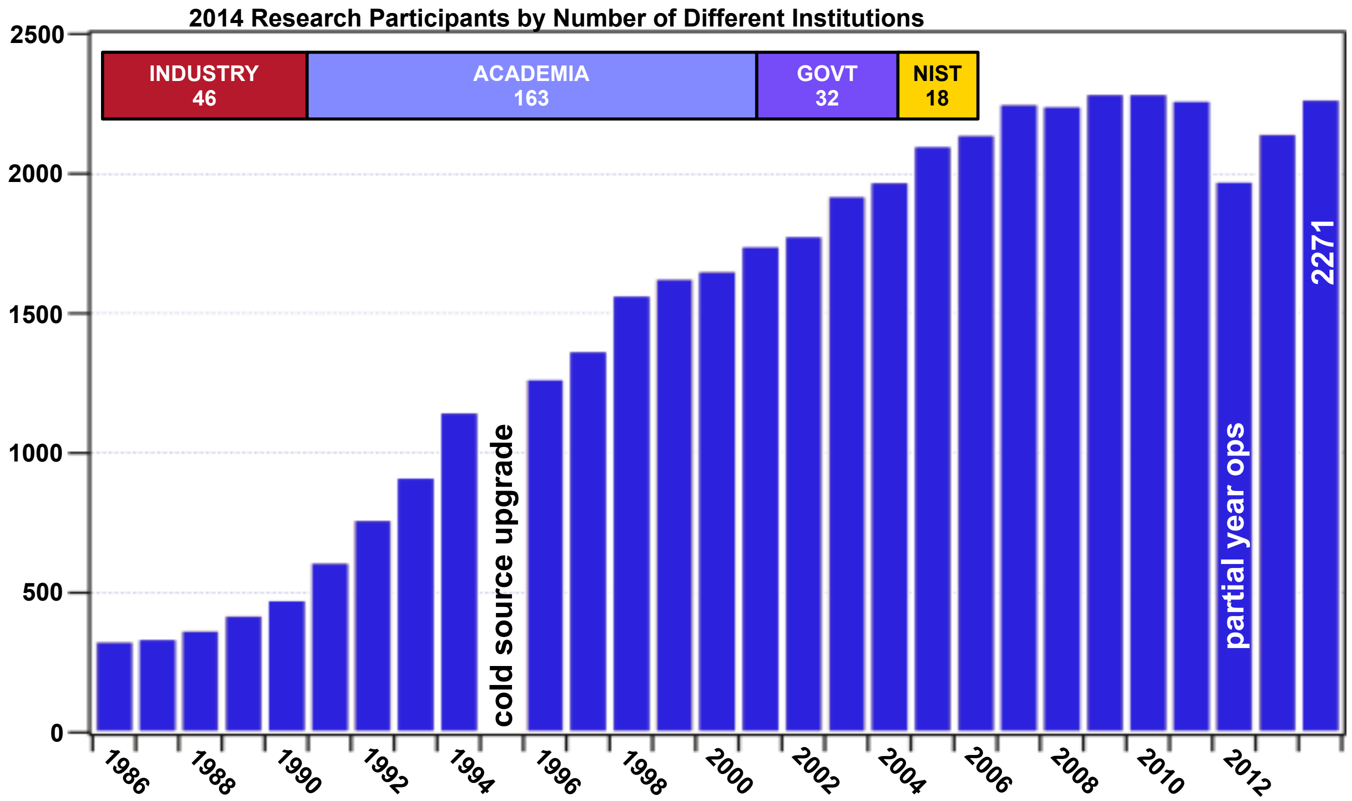
- Neutron scattering
- Neutron activation analysis
- Neutron Imaging
- Fundamental science

International user program
- 28 beam instruments
- ~2,000 users/year
- ~300 publications

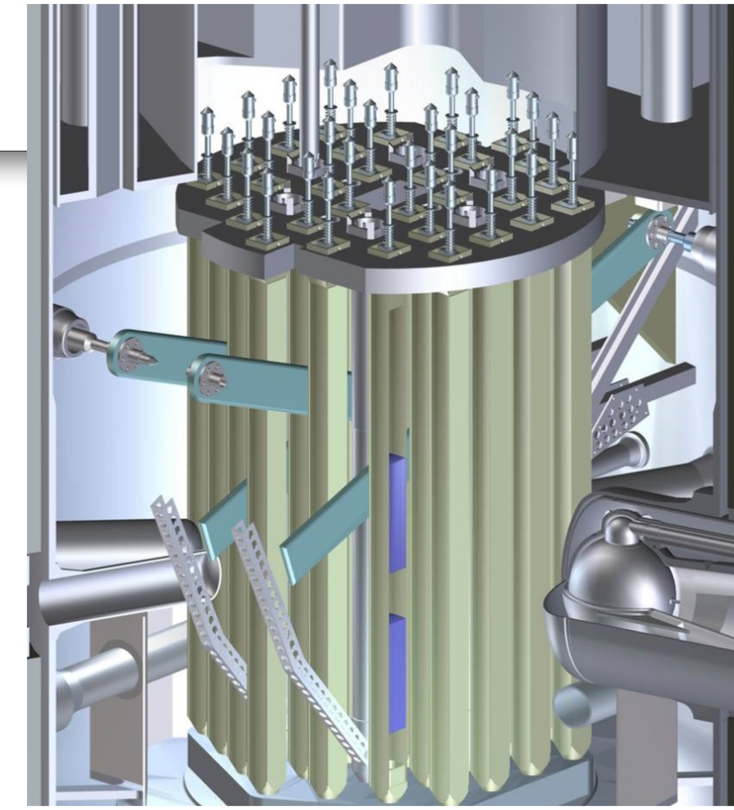
Additional NIST resources:

- Low background counting
- Metrology
- Calibrations:
  - e.g. ~1% activity neutron sources

Allen Astin, Harry Landon, Carl Muehlhause, Bob Carter, Irl Schoonover



Bureau of Standards Reactor (NBSR)

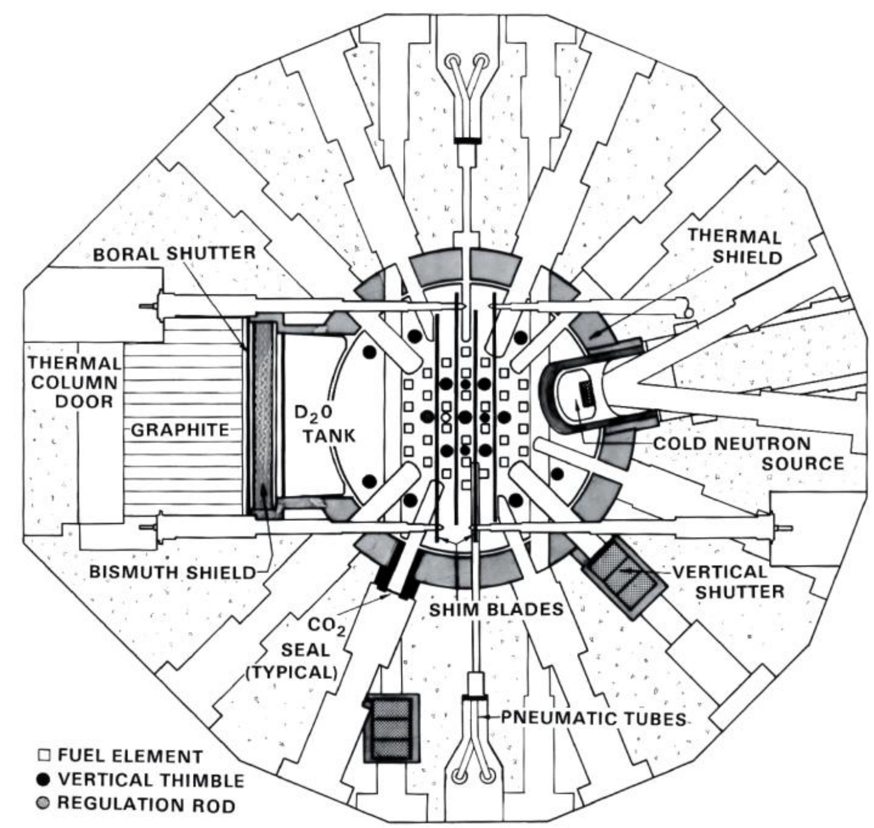


Reactor Type
20 MW_{th} split core HEU reactor (~93% ^{235}U)
Heavy water moderated.
Maximum neutron density ~ few x 1014
power held to 2%
Power monitored w/ thermo-hydraulic system

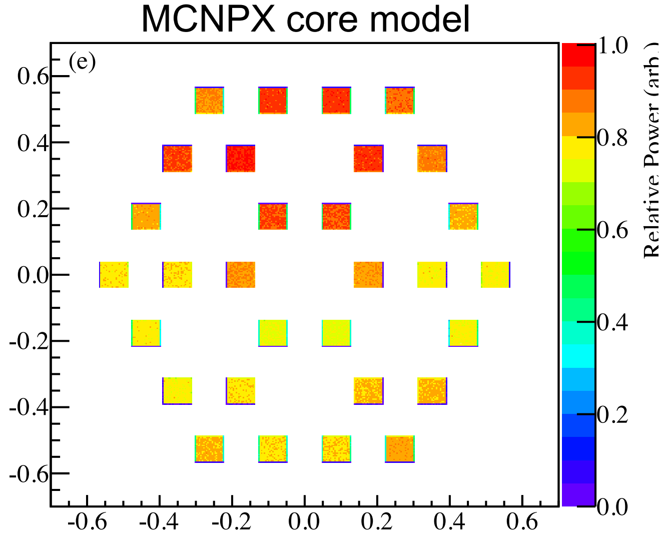
Reactor Core
Hexagonal array 1 m across, ~0.8 m high
30 fuel elements
Every refueling cycle 2 elements replaced, the rest are reshuffled yielding a constant burn pattern

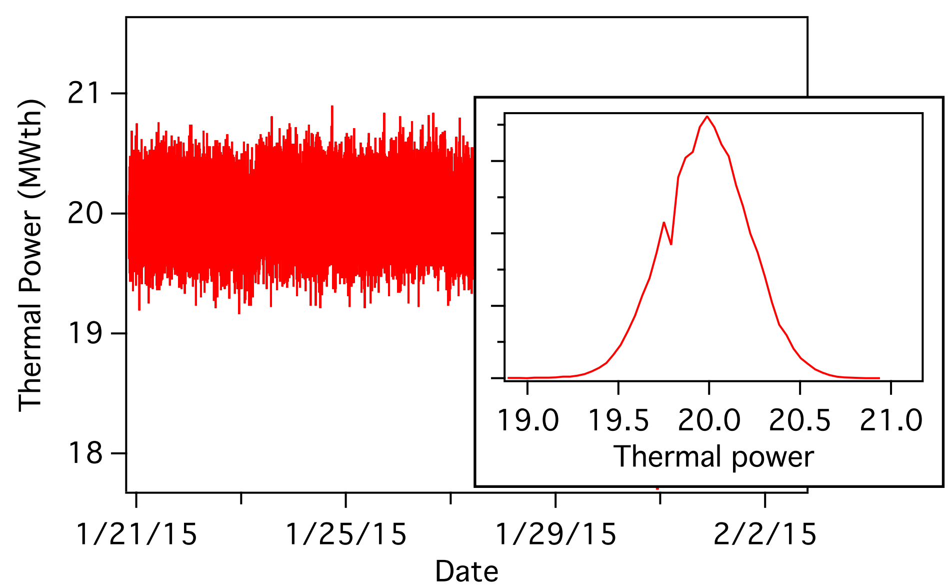
Operating Cycles
Standard cycle is 7 weeks (38 days)
Refueling/maintenance 11 days
99% reliability
Operations for approximately 250+ days per year

PLAN VIEW OF NBS REACTOR



MCNPX core model

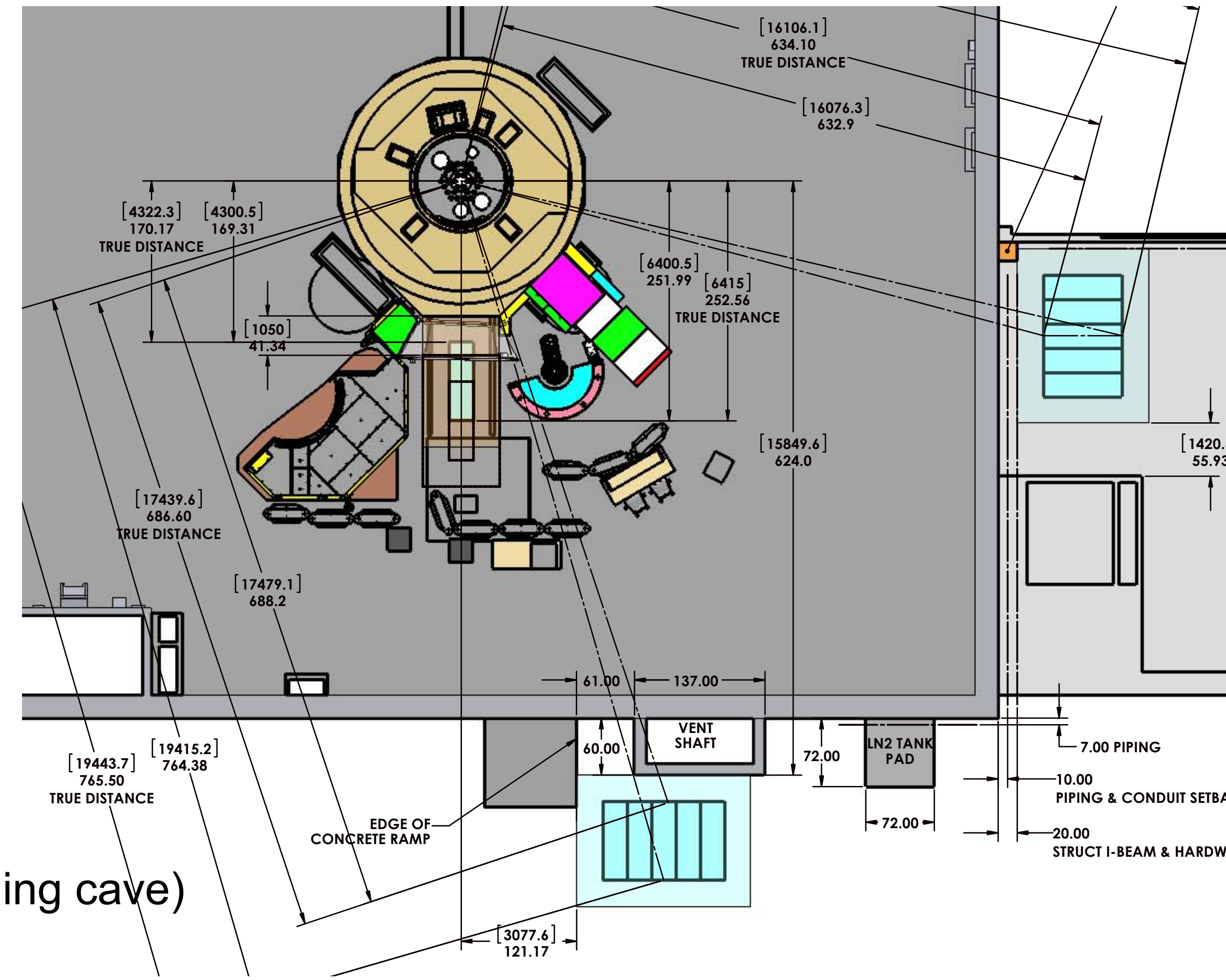


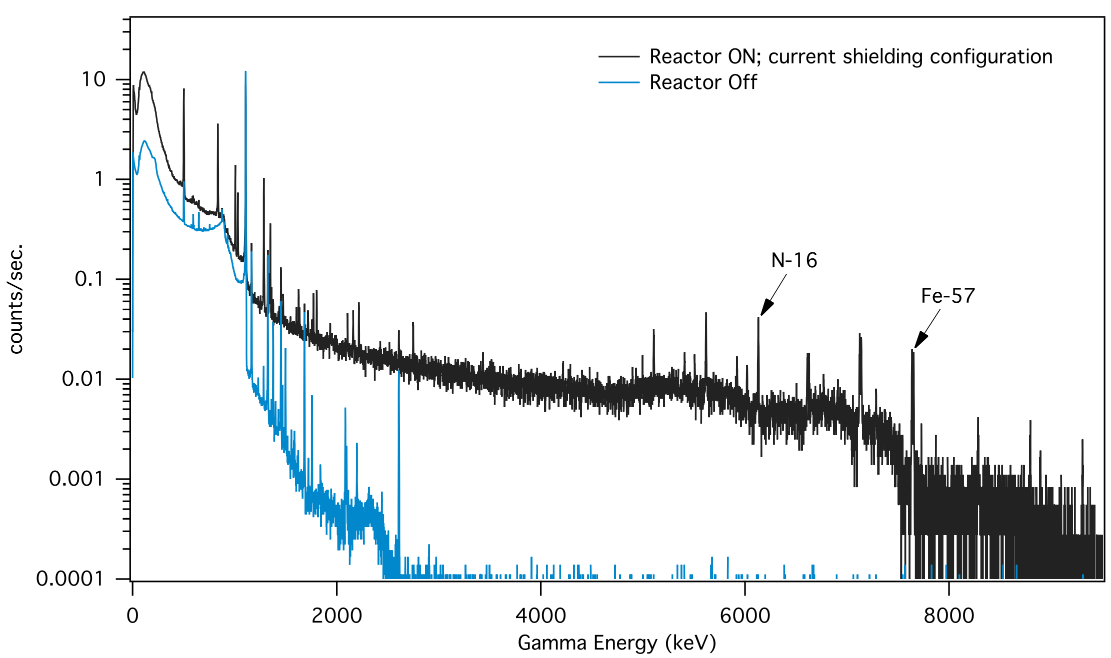


NBSR: Multiple near and far locations available

Thermal column

Approximate near detector option (w/ crate-sized shielding cave)





Near location:

~3.8 m to core center, at grade
15 ton overhead crane service
1,000 - 2,000 psf loading
Inside confinement building - no flammables
Direct truck and forklift access

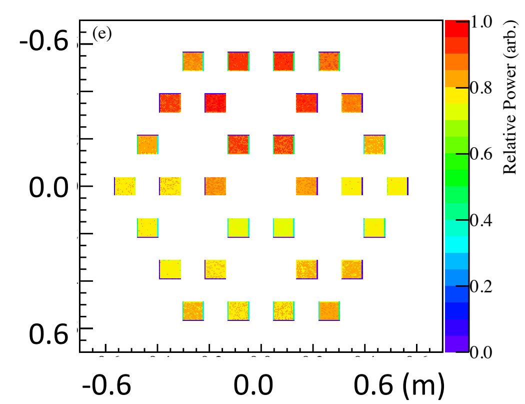
Far location:

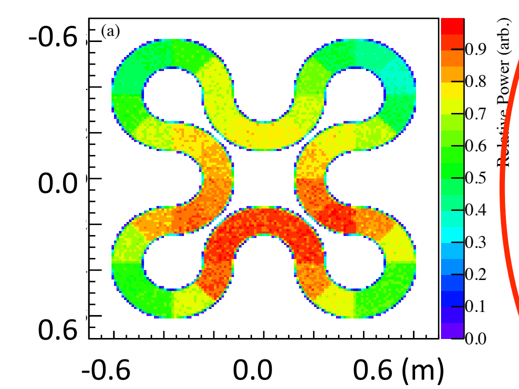
~16 m to core center, approximately at grade
10 ton overhead crane service (high-bay)
1,000 psf loading

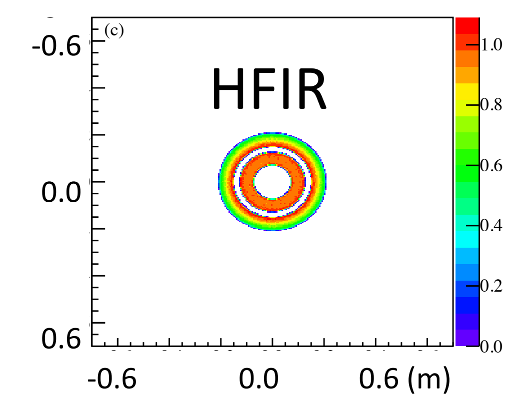
ATR, NIST, and HFIR: Core and flux comparison

Typical commercial core

Site	Power (MW_{th})	Duty Cycle	Near Detector *		Far Detector *	
			Baseline (m)	Avg. Flux	Baseline (m)	Avg. Flux
NIST	20	68%	3.9	1.0	15.5	1.0
HFIR	85	41%	6.7	0.96	18	1.93
ATR	120	68%	9.5	1.31	18.5	4.30

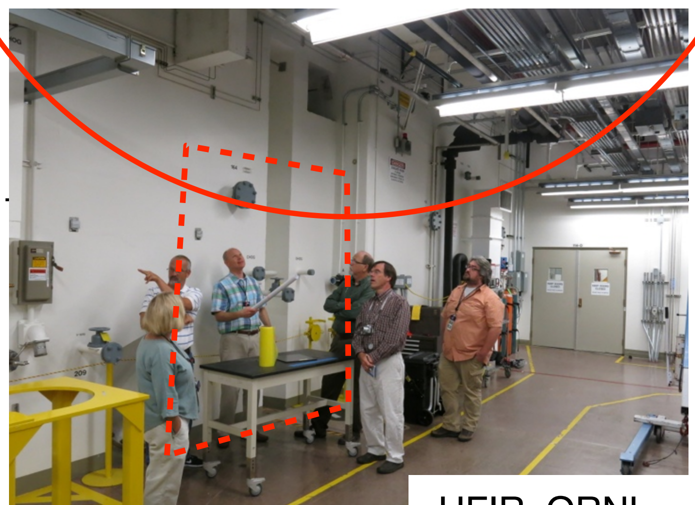






NBSR, NIST

ATR, INL



HFIR, ORNL

* *Baselines listed are somewhat inaccurate to subsequent specification of detector design.*

ATR, NIST, and HFIR: Backgrounds inter-comparison

Expected neutrino signal (near) ~1000/day

Near reactor w/ little to no overburden

Accidental Coincidences

1. Gammas (primarily neutron capture)
2. Fast/thermal neutrons (reactor and cosmogenic)

Correlated events

1. Fast neutrons (reactor and cosmogenic)
2. Cosmics (muons/neutrons + secondaries)
3. Radioisotopes (e.g. ^{8}He, ^{9}Li)

Detailed directional background surveys carried out at all locations

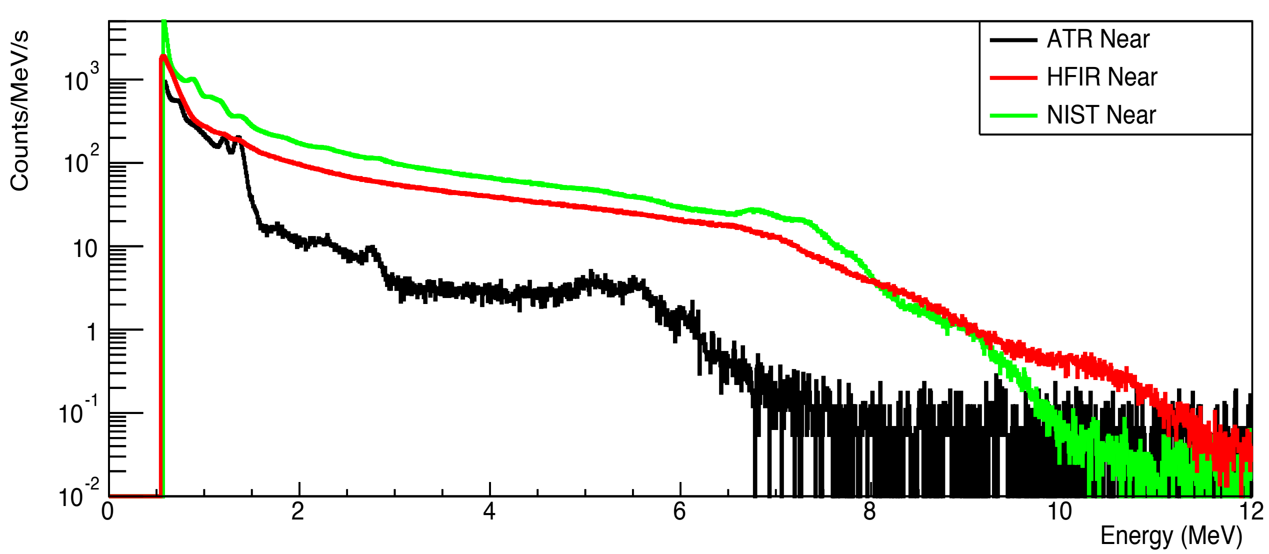
Muon rates

Reactor	Rate at Near Location (Hz)	Rate at Far Location (Hz)
ATR	0.78 ± 0.03	0.68 ± 0.02
HFIR	0.59 ± 0.02	0.71 ± 0.03
NIST	0.56 ± 0.01	0.69 ± 0.01

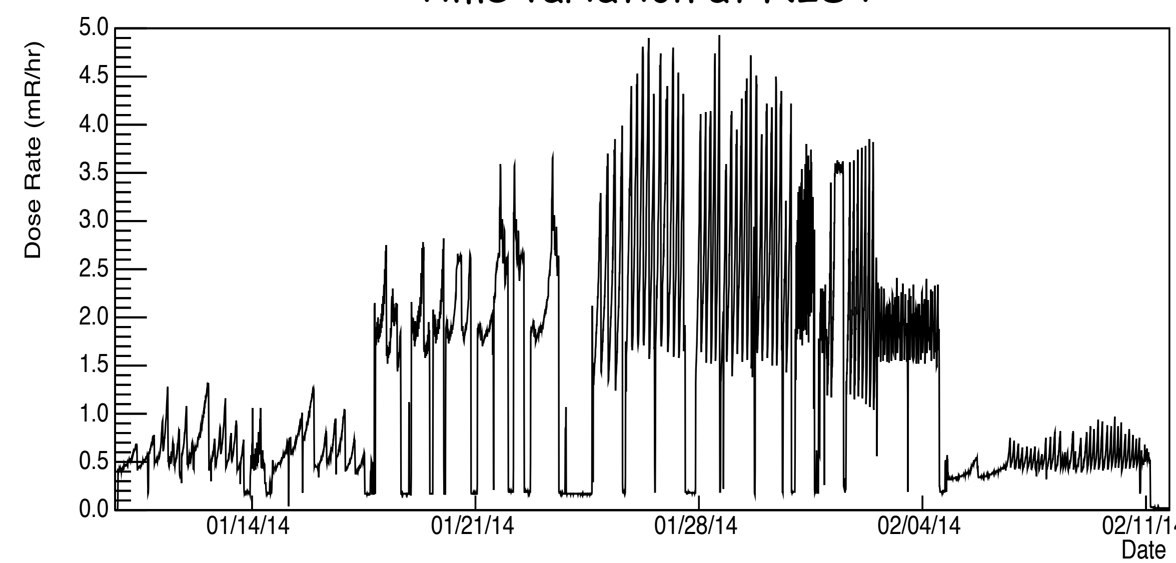
Preliminary

Fast neutron rates

Location	Rate 4 – 14.5 MeV (mHz)	Rate 10-14.5 MeV (mHz)
ATR Near	4.7 ± 0.3	1.0 ± 0.1
HFIR Near	2.2 ± 0.2	0.3 ± 0.1
NIST Near	2.8 ± 0.2	0.8 ± 0.1
ATR Far	1.8 ± 0.2	0.4 ± 0.1
HFIR Far	3.5 ± 0.2	0.6 ± 0.1
NIST Far	2.8 ± 0.2	0.8 ± 0.1



Time variation at NIST



PROSPECT has a comprehensive backgrounds paper in progress

US Research and Test Reactors

Conclusions:

- Conducted a comprehensive survey of likely US locations.
  - Backgrounds
  - Engineering/logistics

- Several US sites offer opportunities for neutrino-physics experiments
  - Short baselines allow for oscillation experiments

- Opportunities for 10 ton scale experiments (Multi-phase, extended sensitivity)
  - Required space and infrastructure exist at three sites

- ATR, NIST and HFIR have all been enthusiastically in support of hosting experiments of these types

- Prototyping and test deployments currently at NIST and HFIR